

Study of critical technology items for an Advanced Earth Orbiting Atmospheric Chemistry/Climate Observatory Using Cryogenic Millimeter/Submillimeter Receivers

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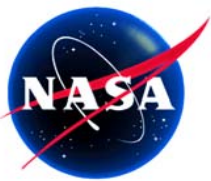
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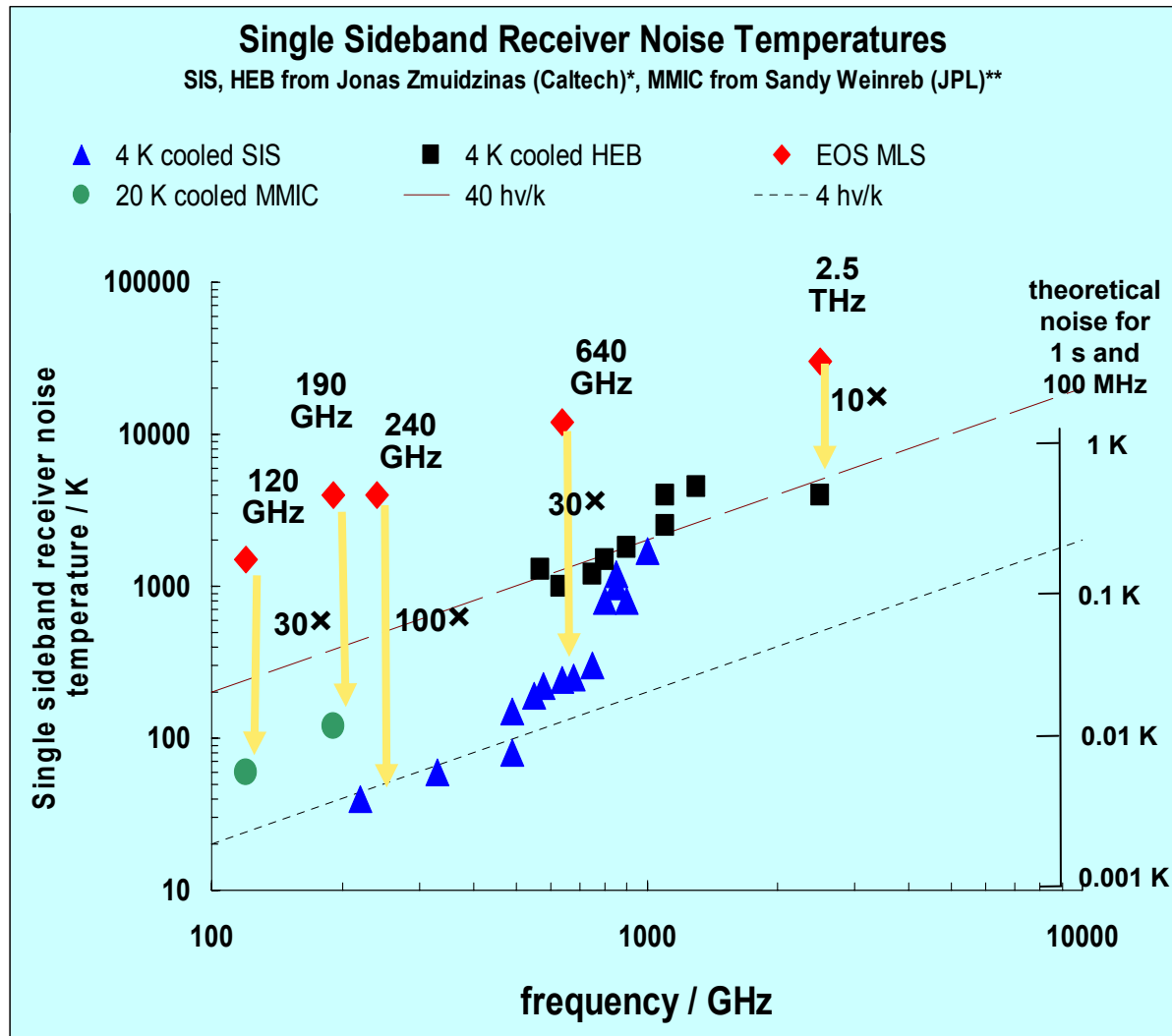
Can ultra-sensitive, cooled receivers be incorporated in modest sized earth observing instruments?



- **The Promise of Cryogenic Receivers for Earth Observing Systems**
 - Performance improvement from cooled receivers
- **Straw-man instrument**
 - 5 band radiometer
 - RFE technology - 2 MMIC, 2 SIS, 1 HEB
 - Low DC power requirement
- **Mechanical layout**
 - A structurally viable concept with low parasitic losses
- **Thermal modeling**
 - Heat load distribution to keep spacecraft bus loading for cooling under 200 Watts
- **Example of what can be done with this Technology**
 - A Microwave Limb Sounder for Tropospheric Studies



Reduce Integration Time by 900 by Cooling Receiver Front Ends



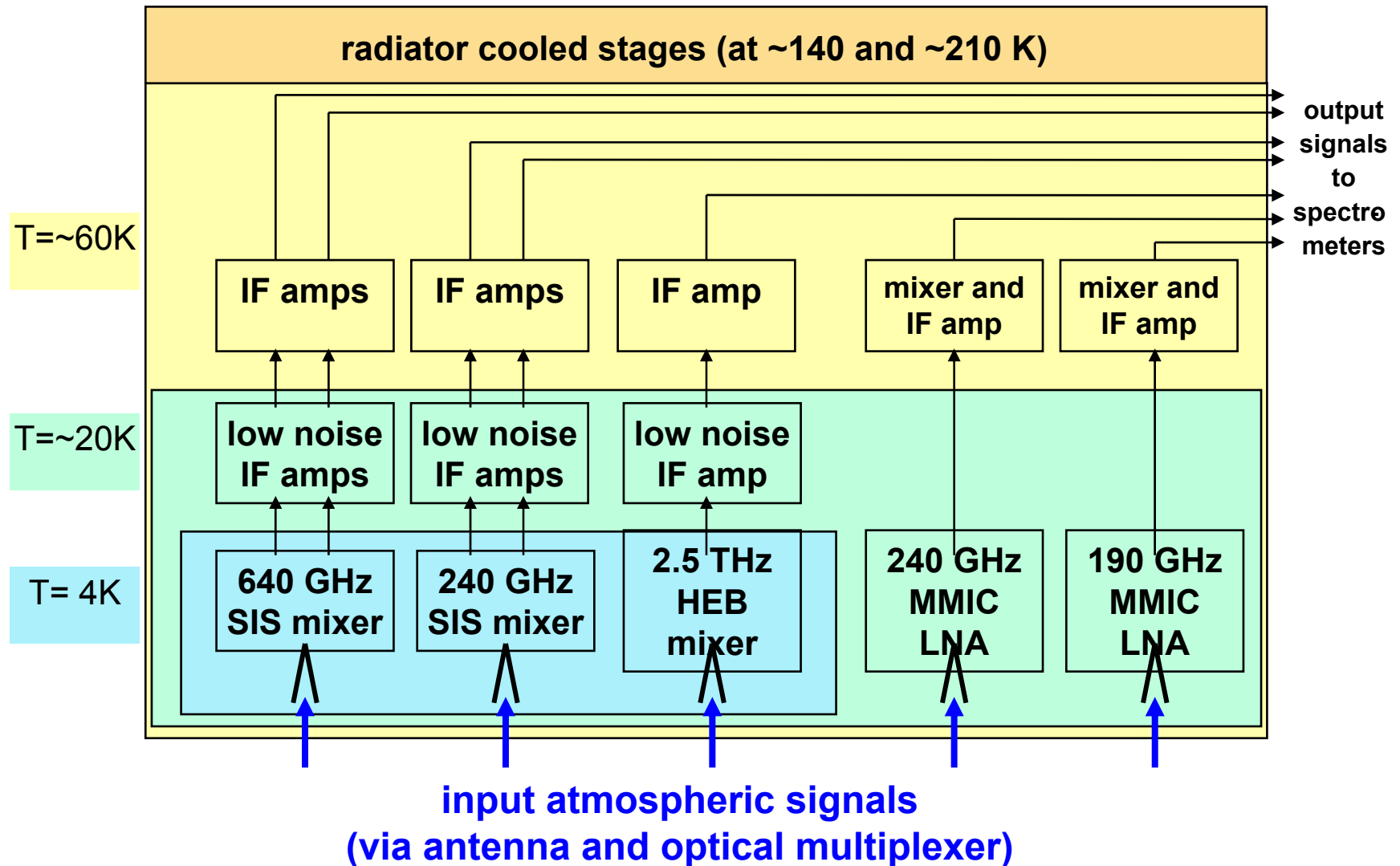
Note: required measurement time decreases as square of the improvement in sensitivity (e.g. 30x sensitivity improvement means 900x less measurement time is required in terms of signal-to-noise, **can do in 1 hour what previously took one month, or do in 1 millisecond what previously took 1 second**).

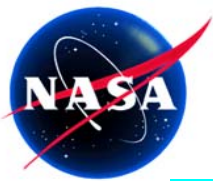


Suite of Radiometer Front Ends

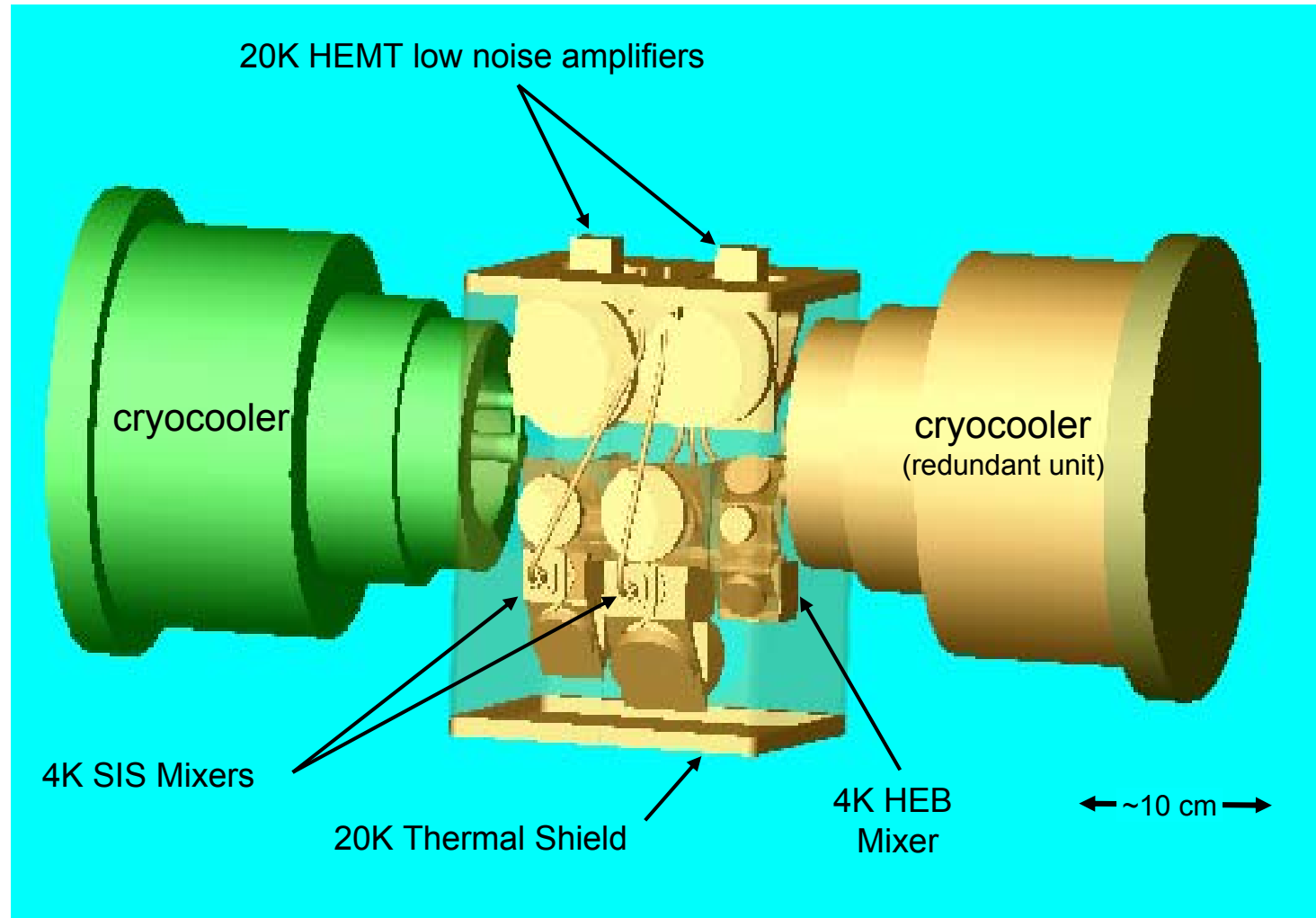


SIS = Superconductor-insulator-superconductor; HEB = Hot electron bolometer
MMIC = monolithic millimeter-wavelength integrated circuit LNA = Low noise amplifier

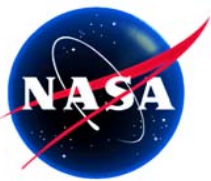




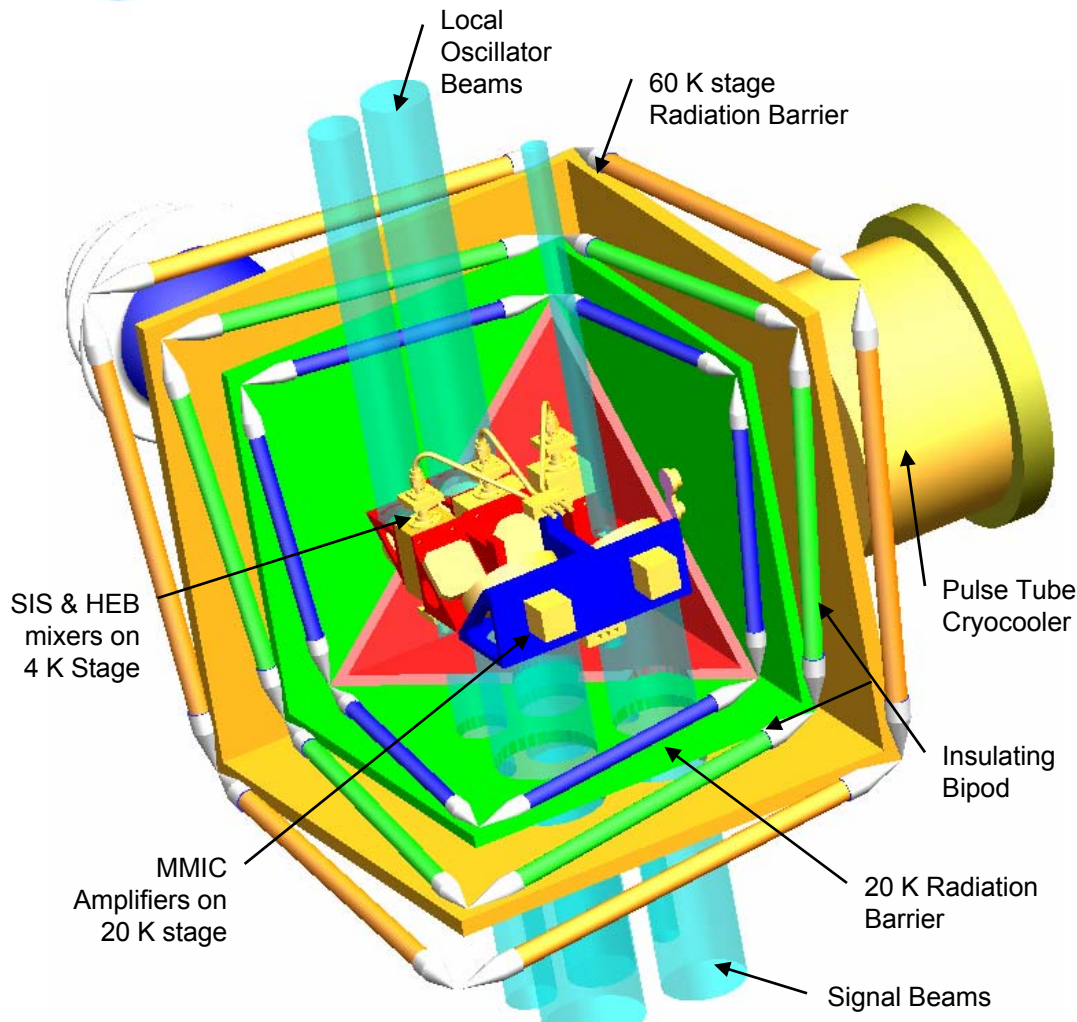
A layout concept for 4 & 20 K stages of cryocooler (concept option with redundant cryocoolers)



We expect to take advantage of developments underway for 6 K coolers for future NASA Code S missions having flight coolers planned for delivery as early as 2007

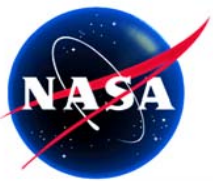


Mechanical Concept 4-60 Kelvin Stages

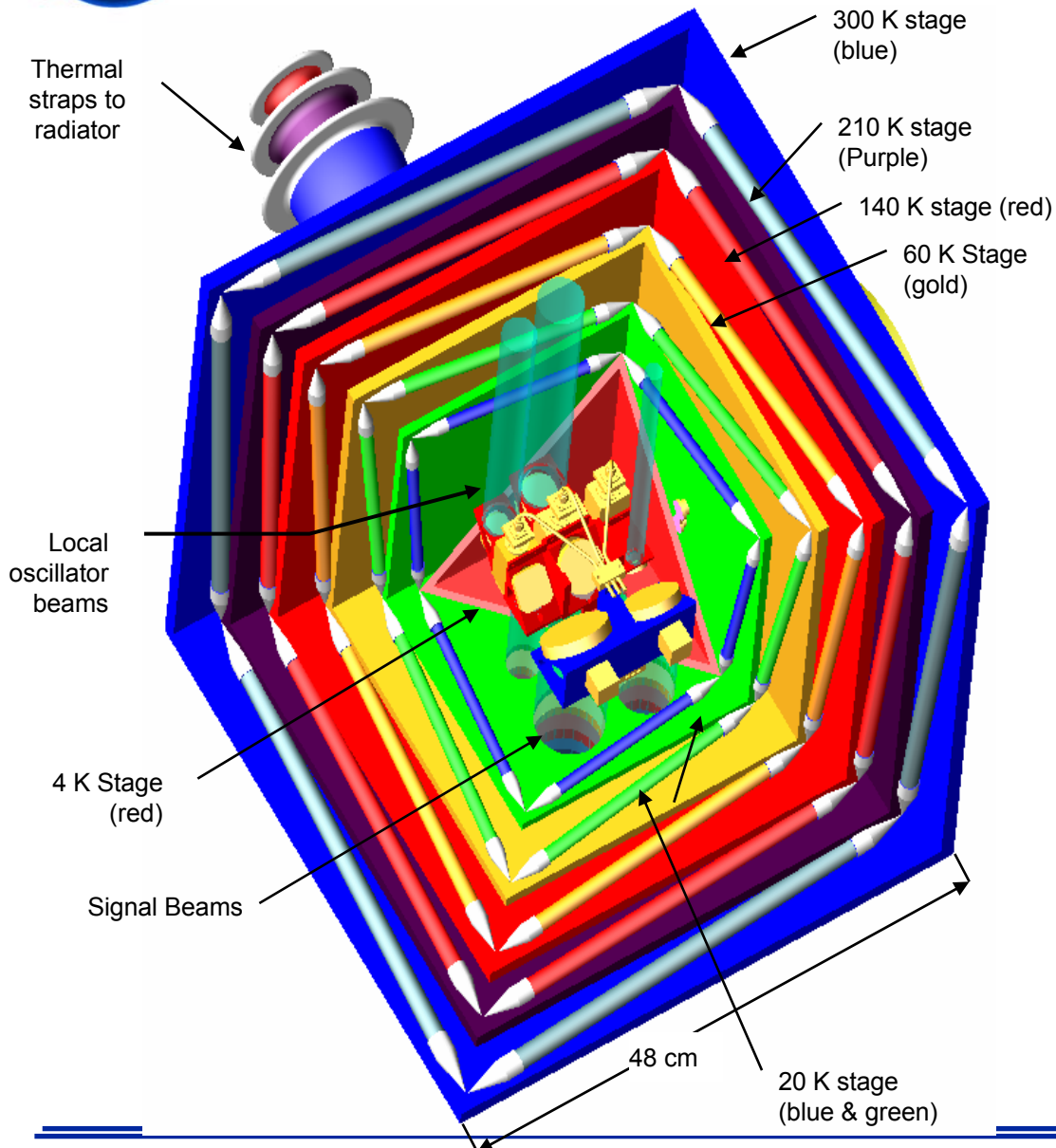


140-300 K stages, redundant cryocooler and half of 20 and 60 K radiation barriers omitted

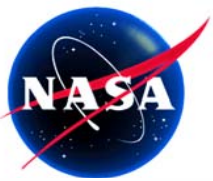
- **3 Bipods support each stage from previous stage.**
 - Ex. Green bipods support the green 20 K radiation barrier from the gold 60 K radiation barrier.
 - Bipods constructed of thermally insulating rods of carbon and fiberglass
- **Radiation barriers built from aluminum isogrids are integral component of support structure.**
- **Only mixers and final optics cooled to 4 K**
- **IF and MMIC amps at 20 K**
- **Local oscillator and signals delivered to receivers quasioptically using parallel beams.**



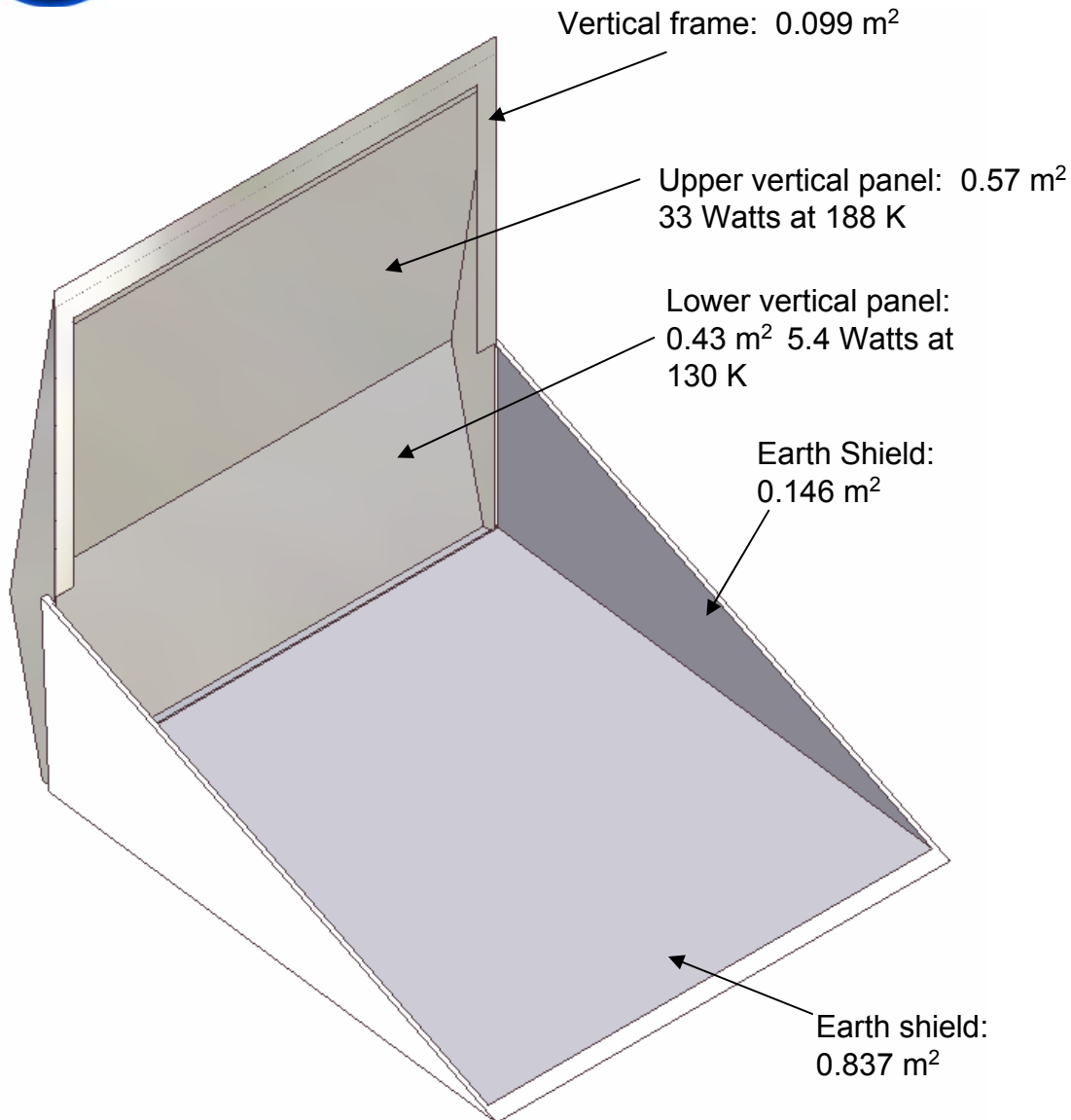
Concept Used for Mechanical Modeling



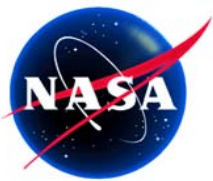
- **3 of 6 faces of each radiation barrier and redundant cooler removed in this view.**
- **Structural analysis gives lowest vibrational mode at 140 Hz for full assembly. (Flight hardware usually specified to have no resonances below 80 Hz.)**
- **Cryocooled stages at 60, 20, and 4 K**
- **Radiatively cooled 210 and 140 K stages**
- **Low pass filters at 210 and 60 K for LO and Signal paths to reduce radiation loading on 20 and 4 K stages**



Radiator



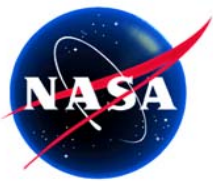
- Radiative cooling for 140 and 210 K stage
- Coolers heat sunk on separate radiator at 300 K



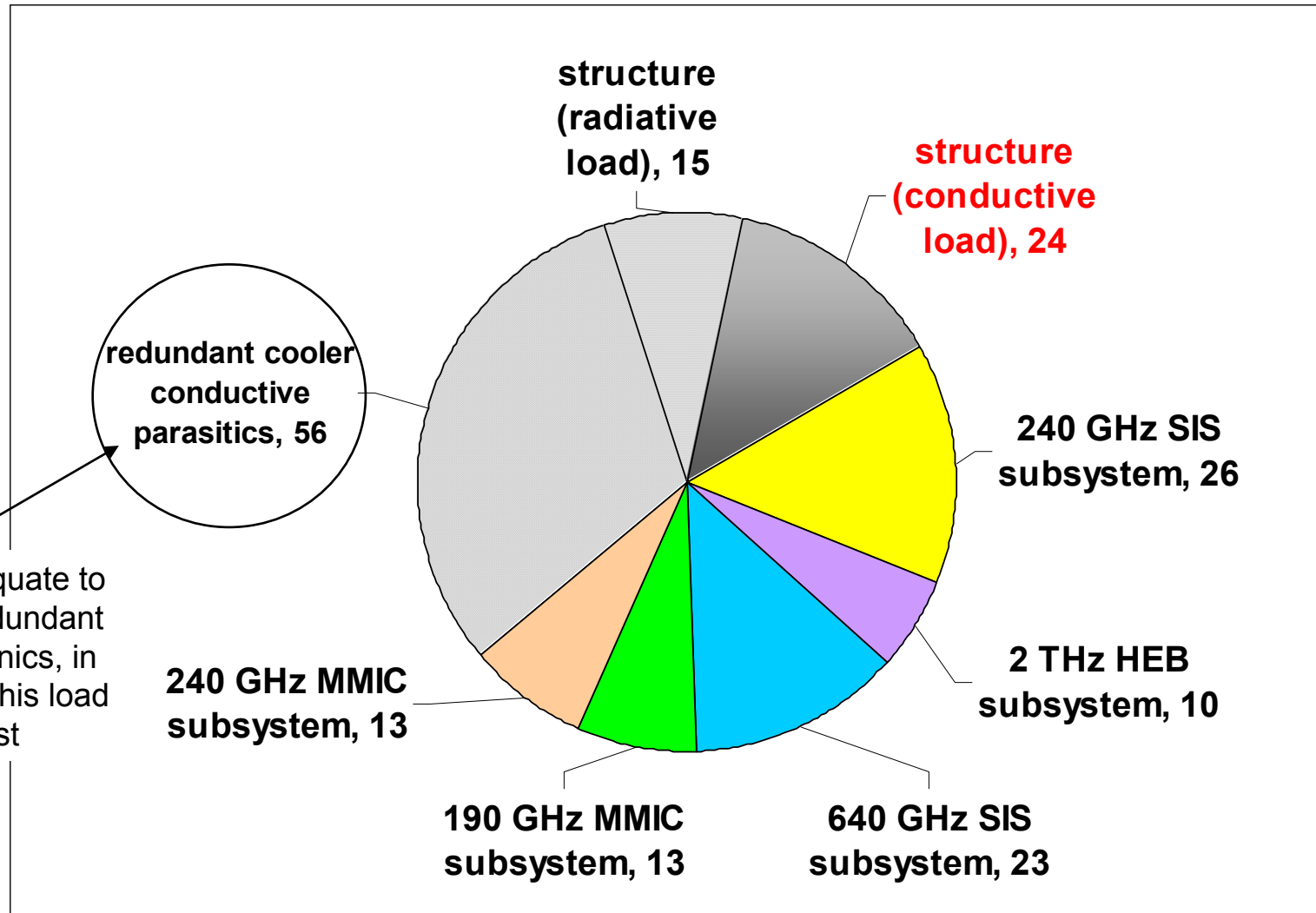
Estimated Heat Loads

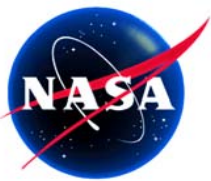


heat load item	cryocooler heat load (mW)			required drive power per item (Watts)	required bus power @ 89% efficiency (Watts)
	4K stage	20 K stage	60K stage		
structure, radiative load	0.8	1.4	216	13	15
structure, conductive load (goal)	2.0	20	80	21	24
redundant cooler	4.4	52	173	50	56
190 GHz MMIC radiometer	0	12	163	12	13
240 GHz MMIC radiometer	0	12	136	10	12
240 GHz SIS radiometer	2.3	21	72	23	26
640 GHz SIS radiometer	2.1	21	34	20	23
2 THz HEB radiometer	0.8	11	18	9	10
TOTAL	12 mW	150 mW	900 mW	160 W	180 W
specific power for each stage	5000	400	40		
drive power per stage (Watts)	60 W	60 W	36 W		
drive power for all stages (Watts)	160 W				
Required bus power with 5 W tare and 89% power supply efficiency	185 W				



Initial estimate of cryocooler power budget for a 5-radiometer SMLS instrument





Concept for a 3rd-generation MLS

(goal is a mission launching ~2010, or shortly thereafter)

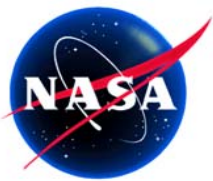


- **Science**

- New tropospheric chemistry measurement capability for regional and global phenomena and their couplings
- Programmable measurement suite to respond to evolving science priorities and atmospheric events
- Continue, in cost-effective way, MLS measurements needed for stratospheric chemistry and climate research

- **Instrument: 'Scanning MLS' (SMLS)**

- Azimuth, as well as vertical, limb scanning
- Radiometers using broadband and cooled mm/submm devices (enabling technology, along with flight cryocoolers)
- Tunable local oscillators

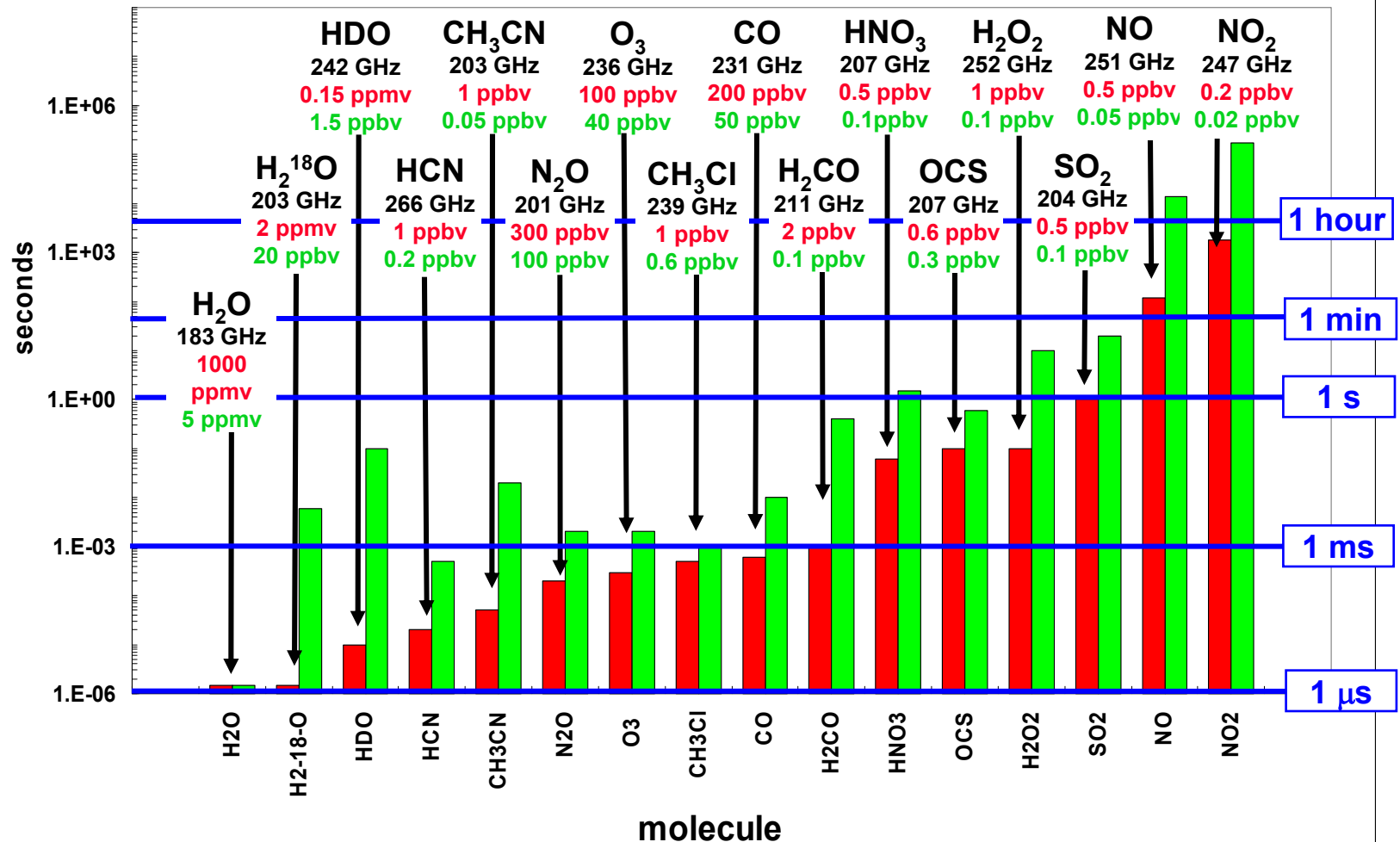


Measurement time required for spectral line S/N=10 for some middle and upper tropospheric chemical species



■ for maximum or polluted abundances

■ for minimum or typical abundances



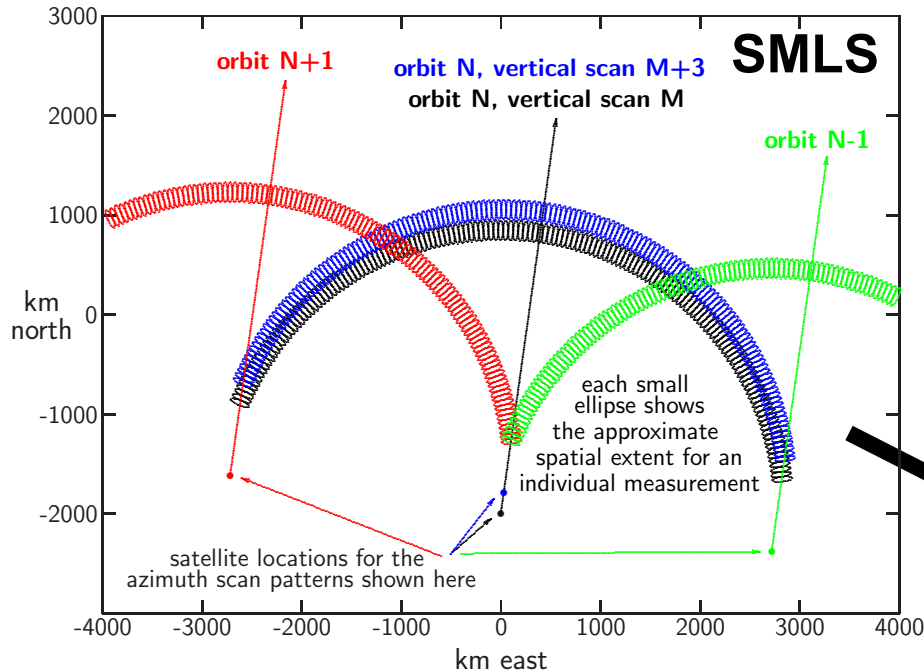


Spatial Coverage



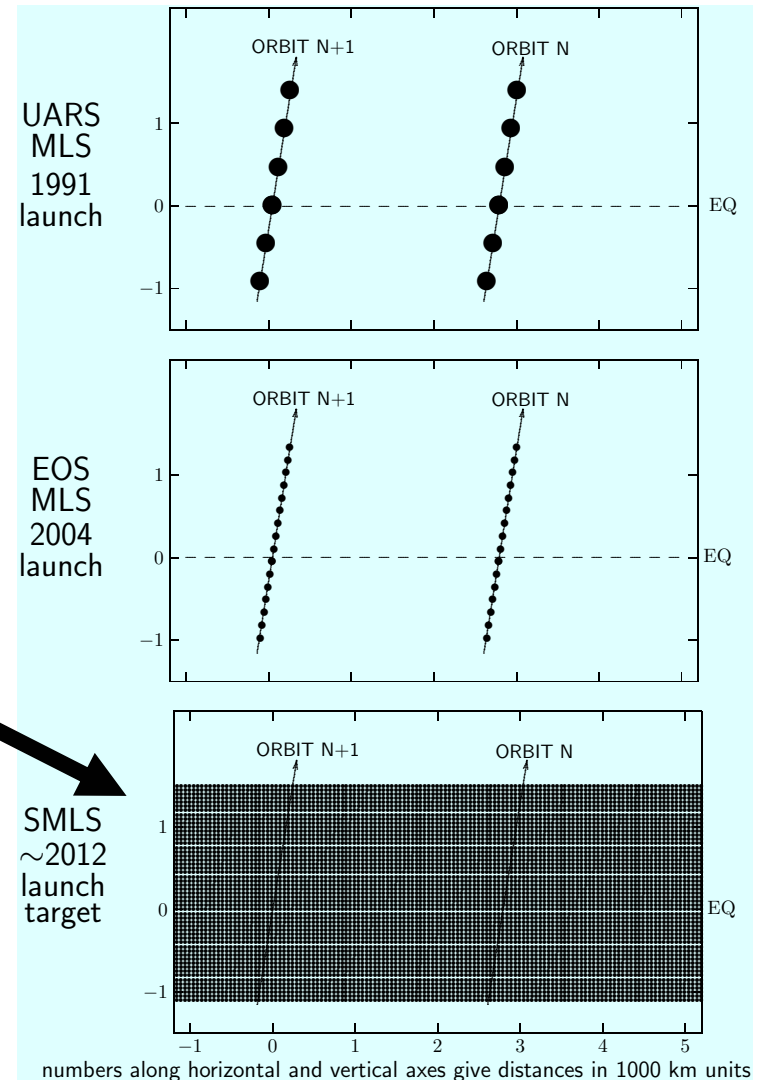
SMLS azimuth and vertical scans are each programmable; one example shown below for portions of adjacent orbits near equator

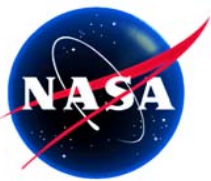
- complete vertical scan (say 20 samples) every ~10s
- complete azimuth scan every ~0.5s, with cal
- measurements every ~2 ms (~50x50km horiz)



- We have yet to decide for sure whether az scan will extend all way to suborbital paths of adjacent orbits, as shown above, or az scans will just 'touch' at ends
- With such a scan, overlapping measurements (in nearly orthogonal directions) from adjacent orbits can overcome line of sight resolution limitations

SMLS compared with UARS and EOS MLS



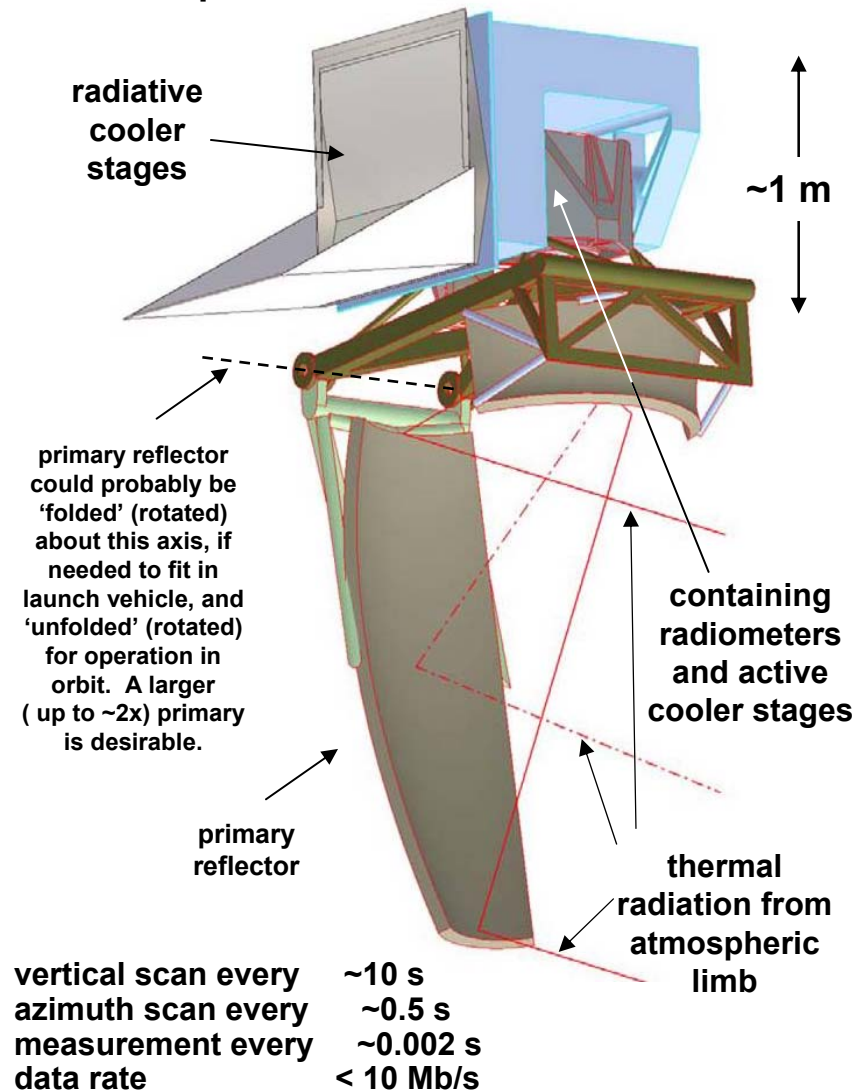


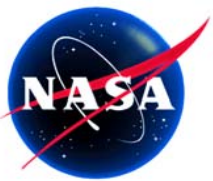
Science

- New capability for tropospheric chemistry measurements on regional and global scales
 - For mid-upper troposphere
 - Measurements in presence of clouds/aerosol that cannot be done by other techniques
 - Complete daily (both day and night with no gaps) global coverage from low Earth orbit
- Cost-effectively continue measurements for stratospheric chemistry and climate research
- Programmable measurement suite (and scan) for easily responding to evolving scientific priorities and atmospheric events

Instrument: 'Scanning MLS'

spectrometer module not shown

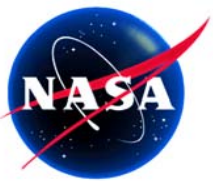




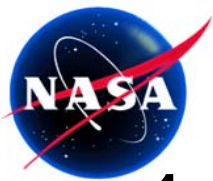
Summary & Future Efforts



- **An instrument with cryogenic receivers would give ~30 fold improvement in sensitivity over present instruments.**
 - Or 900 fold reduction in required integration time
- **We have a viable thermal/mechanical concept requiring for only:**
 - ~40 watts for cooling the cryostat**
 - 10 to 25 watts for cooling each radiometer.**
- **Effort underway to study code-S cooler development for Earth Science applications such as described here.**



Following are backup

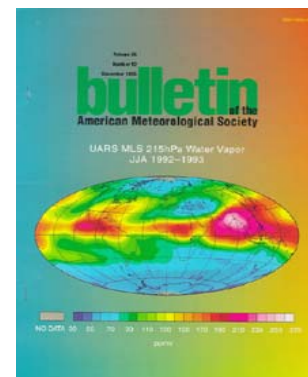


• 1st-generation: UARS MLS (1991)

- primarily for stratospheric chlorine chemistry
- first microwave limb sounding from space, preceded by our aircraft and balloon experiments
- 235 peer-reviewed MLS-related publications to date (listing at <http://mls.jpl.nasa.gov>)



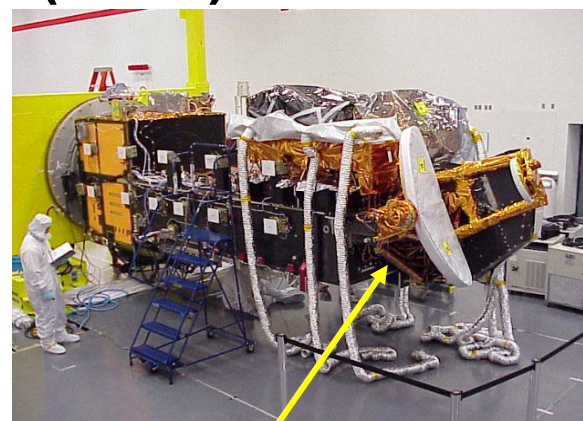
O_3 -destroying ClO



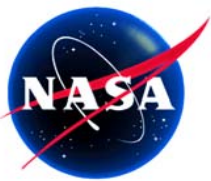
upper trop H_2O

• 2nd-generation: EOS MLS (2004)

- primarily for stratospheric chemistry and climate: important new measurements (OH , HO_2 , BrO , ...) not possible with UARS
- enabling technology: JPL planar devices which allowed measurements throughout the submm wavelength range



EOS MLS on Aura spacecraft



Snapshot of Current Projected SMLS Measurement Capability



Blue and red indicate high confidence of useful measurements.
(Red is for polluted situations.)

Pink indicates further investigation is needed (for tropospheric measurements: mainly of interfering effects - and, for acetone, spectra).

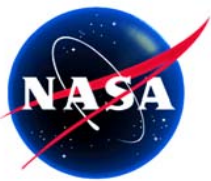
Mid-upper Troposphere

O₃
CO, HCN, CH₃CN,
H₂CO, CH₃COCH₃ (acetone)
CH₃Cl, HCl
SO₂, OCS
HNO₃, NO (?), N₂O
H₂O (and HDO, H₂¹⁸O, H₂¹⁷O), H₂O₂
temperature
cloud ice

Stratosphere

O₃ (and all major isotopes), atomic O
H₂O (HDO, H₂¹⁸O, H₂¹⁷O), OH, HO₂, H₂O₂
N₂O, HNO₃, NO, NO₂, HO₂NO₂
HF, HCl, ClO, CH₃Cl, HOCl,
OCIO, ClONO₂, ClOOCl
BrO, HBr
CO, HCN, CH₃CN
SO₂, OCS, H₂SO₄
temperature, wind

The full suite of measurements that can be done depends on certain technology developments and on the complexity of the instrument selected for flight

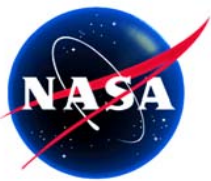


• Noise

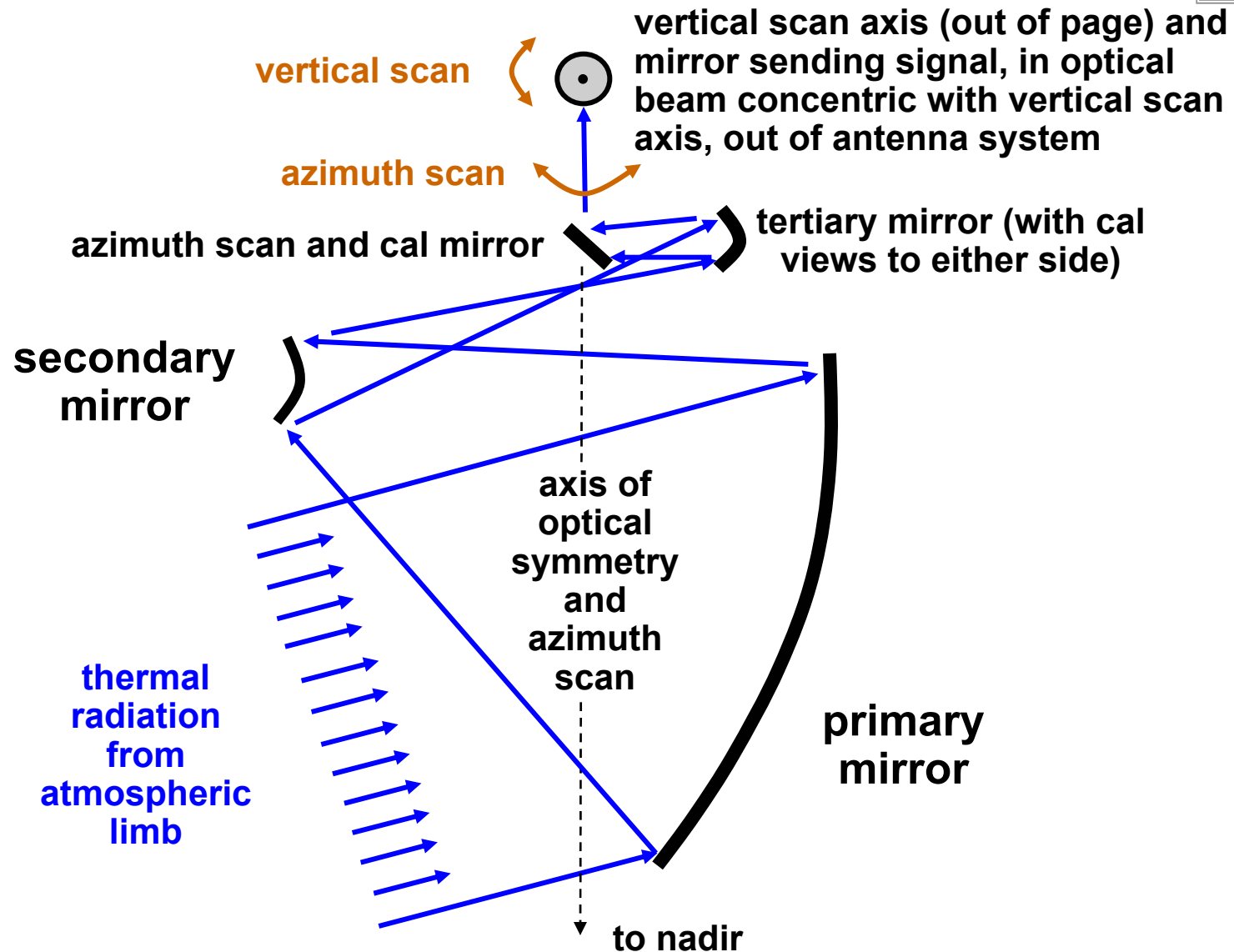
- For upper tropospheric chemistry measurements, I use (for now)
 - $T_{\text{noise}} = 200 \text{ K}$ (100K instrument + 100 K signal)
 - Spectral resolution = 300 MHz (typical half linewidth at 100 hPa)
- Using these, with the 2 ms integration time appropriate for a scan having 150 azimuth samples (for each vertical sample) and 20 vertical samples, the noise on an individual is
 - $\Delta T = 200 / \sqrt{(2 \times 10^3)(3 \times 10^8)} = 0.25 \text{ K}$
- This resolution will be useful for upper trop measurements (e.g., H_2O , T, O_3 , ‘polluted’ abundances of CO, HCN, CH_3Cl , CH_3CN , H_2CO)

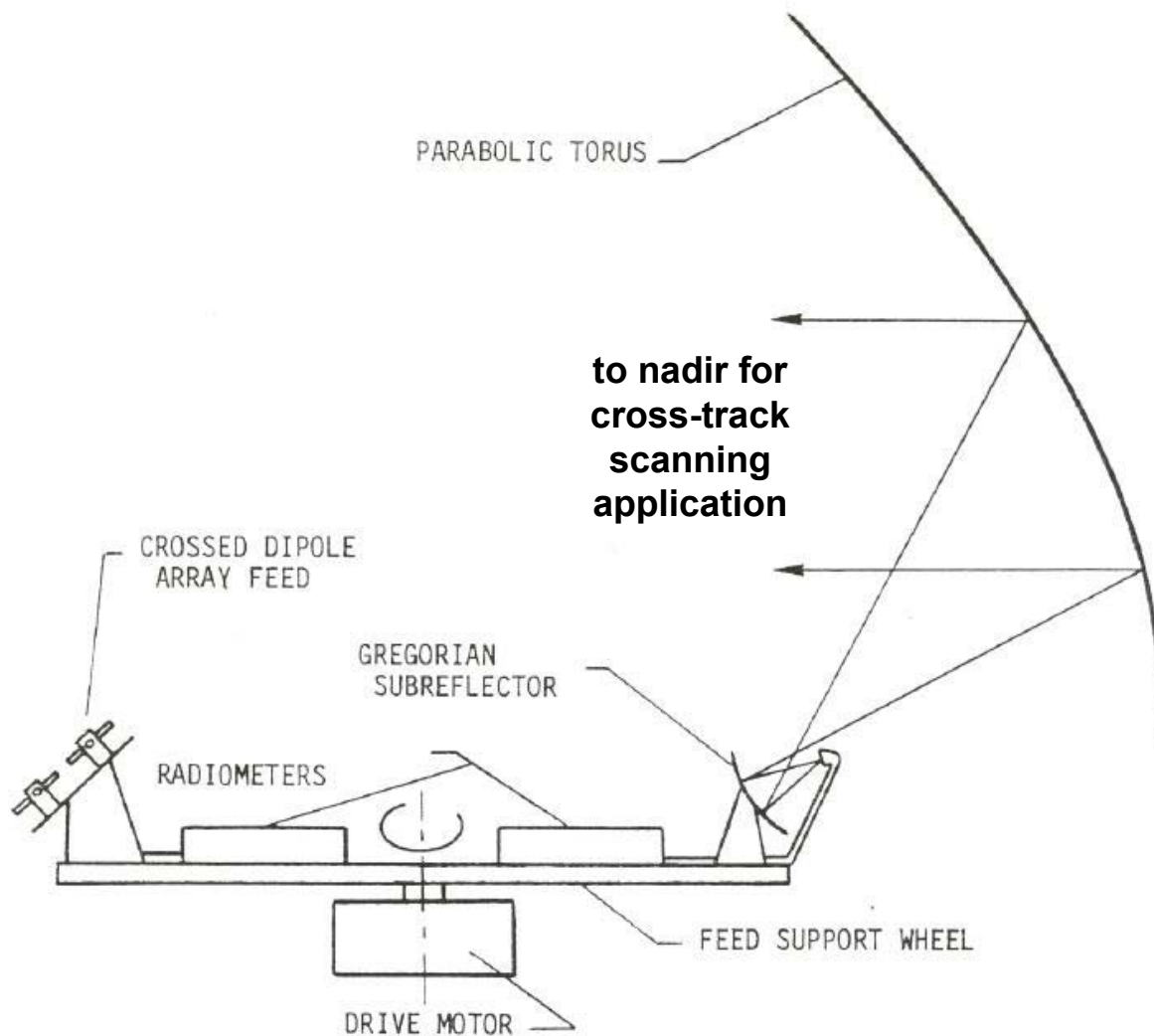
• Data rate

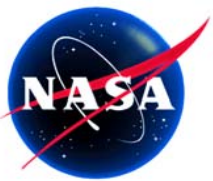
- The data rate is
(number of channels) x (bits per measurement) / (time per measurement)
- Assuming 1000 channels, 14 bit measurement, 2 msec integration time
data rate = $(1000) \times (14) / (0.002) = 7 \times 10^6 \text{ b/s} = 7 \text{ Mb/s}$



Toric Antenna Concept Applied to Azimuth Scanning of Limb



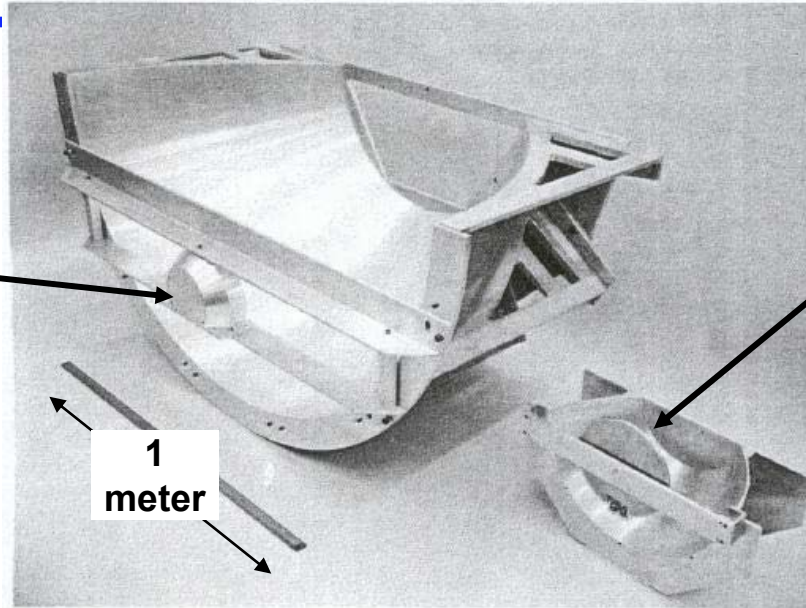




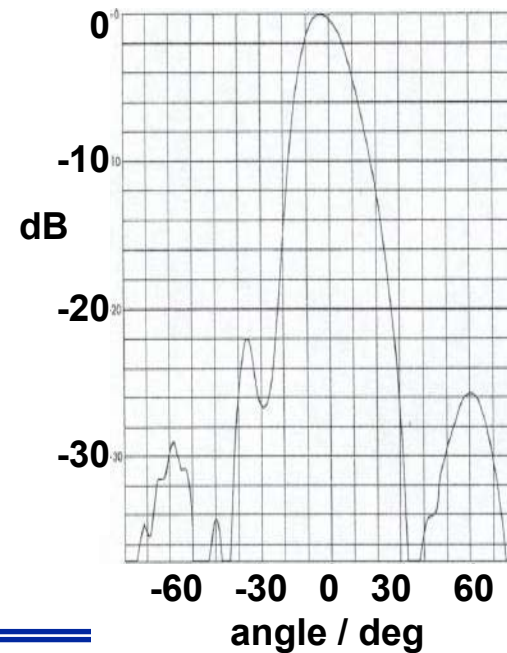
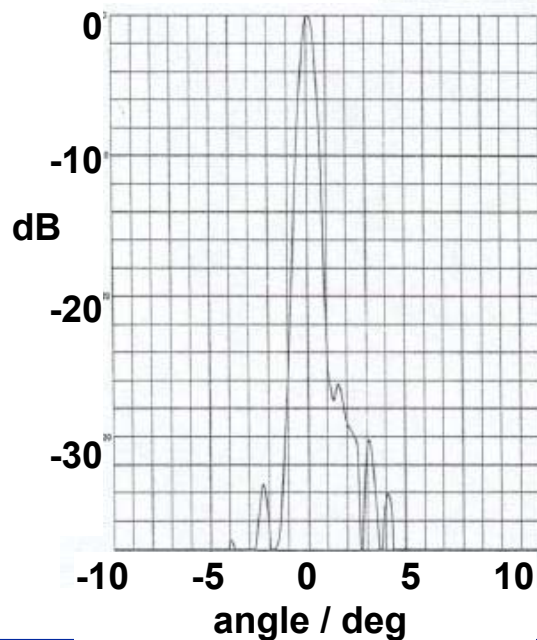
Scanning antenna proof-of-concept models built in 1975



**1/3 scale
model and
measured
30 GHz
pattern
(Gregorian
subreflector
corrects toric
aberration)**

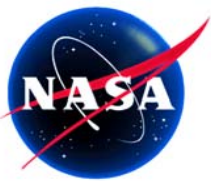


**1/10 scale
model and
measured
6 GHz
pattern
(crossed
dipole array feed
corrects toric
aberration)**



1000





- **Scan period**

- For along-track sampling equal to cross-track sampling, must perform a vertical scan in the time the satellite moves the sampling distance

$$T_{scan} = \frac{\Delta s}{v_{sat}} = \frac{\Delta s}{6.8 \text{ km/s}}$$

- 50 km sampling gives 7.4 s scan period for 700 km orbit (~10 s with retrace)
Note: ~ 3 km/s (at limb) vertical scan rate gives vertical tangent point locus

- **Integration time**

- Let's consider extreme example where we do an azimuth scan over $\pm 75^\circ$, to give global coverage with nearly-orthogonal views. Dividing this 150° total range into 50 km (1°) wide segments gives 150 points in each azimuth scan.
- Also let's consider a scan with 20 samples in the vertical
- With a vertical scan period for 50 km along-track sampling, this gives an integration time per individual measurement sample of
 - $7.4\text{s} / (150 \text{ az} \times 20 \text{ vertical samples}) = 2 \text{ msec}$